

Structuring Classroom Discourse Using Formative Assessment Rubrics

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Abstract. There has been substantial attention paid to students' abilities to engage in a scientific discussion and think critically in a science class. But what constitutes critical thinking in physics? We will discuss a view that critical thinking involves participants (students) becoming increasingly involved in a specialized form of argument that has fixed epistemic rules, but whose rules are seldom made explicit within the physics community that uses them. We will then discuss one method of making the epistemic rules of physics explicit for students by using formative assessment rubrics. We will provide some examples of how these rubrics can be implemented in a physics class and how students were able to transfer critical thinking abilities beyond the physics classroom.

Keywords: Physics education, scientific abilities, learning community, epistemology

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INTRODUCTION

It has been roughly twenty years since the ideas of cognitive apprenticeship [1] and legitimate peripheral participation [2] were proposed as frameworks for instruction. No longer were instructors going to focus on teaching students, but they would become co-participants in a learning community comprised of instructor and students. The instructor would function like a master craftsman, modeling expert behavior, and coaching students, while students shared ideas and helped each other. Yet the details of how this should happen in a physics class remain unclear. In this paper we will discuss some important factors that we believe need more attention if we want to implement the ideas of cognitive apprenticeship and legitimate peripheral participation in building a learning community. We will then give examples of how we built a physics learning community and moderated the discourse in an introductory physics class using formative assessment rubrics.

THEORY

If physics is a community of expert learners, what is it that binds this community together and gives it its shared sense of identity? We would like to propose that the binding factor is a shared set of socially transmitted and negotiated "meta-discursive" [3] epistemic rules and epistemic activities that physicists engage in [4,5]. Participants in the physics

community become enculturated into these epistemic rules. New knowledge is generated by engaging in the accepted set of activities that are sanctioned by those epistemic rules [5]. Physics knowledge is understood by the activities from which it was generated.

What are the elements of the social activity that physicists must learn in order to participate in the physics community? 1) Hypotheses that cannot be tested by experiment are generally not acceptable. Physicists are always generating hypotheses, and to gain acceptance, they need to be falsifiable or testable. 2) Purely descriptive theories of phenomena are derided in the community as "stamp collecting [6]." Physics needs to explain *how* things happen, not just that they do happen. 3) Physics is not exclusively inductive or deductive, but has elements of both. Experiment and theory are reflexively conjoined. a) Experiments inform theory as physicists try to account for unexpected experimental phenomena. b) Theory informs experiment as physicists who propose new hypotheses, suggest ways in which their hypotheses might be tested [7]. 4) Experimental outcomes have to be reproducible by others. An experimental result that one physicist obtains and publishes will be considered anomalous or maybe fraudulent if other physicists find they are unable to reproduce the experimental result. This list is not an exhaustive account of all the epistemic rules of physics. A more complete description of what physicists do may be found in [8].

In the light of this description of the epistemic rules of physics, we would like to consider the learning goal of turning students into “critical thinkers.” We want students to develop epistemologically [9,10] as well as learn physics so that they become critical thinkers and approach life outside of the classroom with the same questioning attitude that we have tried to cultivate in the classroom. In physics, this questioning attitude or skepticism is ideally constrained by the epistemic rules of physics. In other words, it is unreasonable for a physicist to say “I think you’re wrong because I believe it from the bottom of my heart.” An effective physics skeptic should say things like “Here is an experiment that could test your hypothesis,” or “I cannot reproduce your result even though I followed the exact description you have in your paper,” or “you have analyzed your data incorrectly for reasons X and Y.” Ideally the arguments that might follow are grounded in the epistemic rules of physics.

The point we’re trying to make is this: Turning students into critical thinkers is equivalent to inducting them into the epistemic rules of physics. In this view, our task as instructors is clear, but not easy. We want students to start thinking like physicists. This means that we want them to argue and think critically following epistemic rules that are seldom made clear. We want students to be able to propose multiple testable hypotheses to explain the data, examine their data analysis, reconsider experimental results in the light of underlying assumptions that they made, and evaluate their work by taking limiting cases, etc... In summary we need to find a way to enculturate the students into these epistemic rules and activities of physics so that they become more adept at playing the game [4] of physics. These rules have been referred to as “scientific abilities.” [8], or as the “habits of mind” of a physicist [11].

SCIENTIFIC ABILITIES RUBRICS

There are probably many ways to help students develop the habits of mind of a physicist. We want to describe one method that has been shown to be successful in helping students develop these [12]. In our approach students use scientific abilities rubrics to guide their learning and the instructor uses the same rubrics as a formative assessment tool to provide feedback. While the original scientific abilities rubrics were developed for students to evaluate their laboratory work [8], they may be adapted to all facets of the class including setting learning goals, all grading, and moderation of whole-class discussions. The rubrics [8] take a broad scientific “habit of mind” such as “*the ability to evaluate models, equations, solutions, and claims*”

and break it down into several sub-abilities such as “*Is able to use a unit analysis to correct an equation which is not self-consistent.*” For each scientific ability, sub-abilities are laid out vertically down the left side of a table grid with a grading scale across the top that has columns for “*missing,*” “*inadequate,*” “*needs improvement,*” and “*adequate.*” Students are required to evaluate their own work on relevant sub-abilities and the instructor also examines their work on the same set of sub-abilities and provides feedback on how to improve. With the aid of the rubrics the epistemic rules and activities of physics become explicit in a way that allows students to continually re-examine and improve upon their own work while developing a deeper understanding of the sub-abilities.

IMPLEMENTATION

The class in which we created this scientific learning community was a calculus-based introductory physics course consisting of 30 students at Florida International University. Most students were drawn from underrepresented minorities in physics. It was taught in a studio setting using the *ISLE* curriculum [13]. Students worked in groups of 3 or 4 while the instructor and assistants circulated about the classroom offering scaffolding as needed.

Whole-Class Discussions

Whole-class discussions were probably the most important place where students could practice applying the epistemic rules of physics. The mechanics of this involved students working on *ISLE* activities in individual groups, and putting their ideas on whiteboards. At the appropriate time, the instructor called the students to gather in a circle for a whole-class discussion where student groups presented their ideas to each other and discussed their ideas with each other. The instructor encouraged students to keep the discussion within the epistemic rules of physics. For example, the instructor would remind students with questions such as “what were your assumptions?” “How would you evaluate student X’s result?” “Is there another group who has an alternative hypothesis to explain these data?” and so on and so forth. Sometimes multiple alternative hypotheses were “seeded” [14] in different groups to promote discussion and get students to think about how to design different experiments to test and eliminate hypotheses. All these questions were directly based on specific scientific sub-abilities in the scientific abilities rubrics. Students also used the same rubrics when they did homework, designed lab

experiments, etc. Rubric-based scaffolding was reduced as the semester progressed encouraging students to start asking those same questions of each other without prompting. At several instances in the semester, this idea was openly discussed with the students so that they were aware of the expectation that they should conduct their discussions in accordance with the sub-abilities in the scientific abilities rubrics.

Homework

Another key area in which we tried to make explicit the epistemology of physics was in homework. While specific homework exercises and problems were selected because they gave students practice in one or more scientific abilities, each homework problem was graded the same way using three criteria: clarity, consistency, and evaluation. Students were never graded on whether they got a “correct” answer or not. *Clarity* was framed as “if you were to give this problem to somebody who had no idea how to solve it, could they understand what you did without too much effort?” We also let students know that they were practicing clarity to improve their communication ability. *Consistency* implied, for example that the signs in a Newton’s second law equation should be consistent with the force diagram drawn by the same student, or a force diagram should be consistent with the written description of the situation in the problem. The *evaluation* criterion required students to evaluate their results by either a) a limiting or special case, b) unit analysis, or c) some argument that the result is physically reasonable. This grading scheme not only got students away from “answer seeking” mode, but was very quick and easy to administer. We graded the homework on a simplified scale of “missing/inadequate,” (0 points) “needs improvement,” (0.5 points) and “adequate” (1 point). As students improved on these three criteria, homework grading became incredibly easy since their work was so clear, taking the guessing out of grading. Not only that, but the quality of homework got better and better because students started to find and fix their own inconsistencies.

EVIDENCE OF SUCCESS

The data from this research is still in the early stages of analysis. However, a number of factors suggest that what we were doing was working as intended to some degree.

FCI Scores

Students entered the class with a low pre-test score of 26% on the force concept inventory (FCI) [15]. The normalized gain for the class was $g = 0.37$ which places the course within the range of scores typically associated with “interactive engagement” instructional methods [16].

Student Attitudes

Such radical reform as undertaken in this course often leads to student resistance [17]. However, in our class this was not the typical case. After the first semester out of 30 students, 19 wrote extensive comments on the course evaluation forms. Only 2 of those comments were the type of negative comment we associate with student resistance to reform, like,

“Although it’s a [reformed] course, there should be more lecturing involved.”

In contrast, the other 17 comments were overwhelmingly positive. For example,

“The structure of the class was very different from what I’ve been used to, but it was actually very motivating and made me want to try harder so that I wouldn’t let down any of the other members of the group or the professor.”

Development and Transfer of Critical Thinking

We conducted interviews with several students after the end of the second semester. These interviews revealed a) evidence that they had learned to think like a physicist, b) they were seeing the relevance of the processes they had learned in physics in other classes.

In his interview, Henry revealed a deep understanding of the nature of physics:

“We have to come up with the best model we can based on the equipment we have available to test the model...We still have to accept that fundamentally our models might be just wrong.”

Ernest discussed that he felt that he was approaching life outside of the class differently because of his experience in the physics class:

“I do think about things differently. I tend to ask myself more questions in my head. Does that seem reasonable? How did he or she make that connection? Does what he or she is saying really represent what they just showed me...I apply this overall to my social life. You

know, when I'm talking to anybody about anything..."

Alice discussed how she found herself and other classmates using the analogical reasoning process that they had learned in physics in other classes:

"The funny thing is like we started using analogies in other classes like our cell bio class. So it came up in other classes and I'm like, oh my gosh, that's physics, I learned that in physics class. So ya, kinda not only just for physics, you can use it in your other classes."

Student Motivation

Most importantly, students felt that they were motivated to learn in the physics class. Henry talked about the affect the class had on him:

"I feel I gained a lot from the class, but I put in a lot of effort. I would find myself, even when I was driving home or walking in between classes thinking about things we'd done [in class]."

In his interview, Ernest discussed how he dealt with a particularly difficult question on the photoelectric effect that appeared on the final exam. In fact, students had not studied the photoelectric effect at all in class.

"That was a question that would stick in my head, because that deals with the photoelectric effect, right? ...the frustration comes with the fact that I'm being challenged. I'm frustrated that I can't get the answer, but that pushes me even more to find the answer. So without that frustration, I don't know if I'd still be pursuing the answer. The frustration comes with it and it's kind of an exciting happy frustration, as strange as that sounds ... but, you know, I have to keep on working because I'm going to get this answer...How can I be mad about something like that. I mean, isn't the whole point of college to give you the experience of past people and to give you that practice and get you in that mind set so that you can tackle new problems out in the field?"

DISCUSSION

In this paper, we have offered an idea of what constitutes critical thinking in physics and discussed how to foster this process in a physics class. While data is limited, evidence suggests that students have learned the physics content as well as undergoing an epistemological shift. In addition, students appear to

enjoy the class, are motivated to learn, and show that they are transferring their nascent critical thinking skills to other contexts outside of their physics class.

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REFERENCES

1. A. Collins, J. S. Brown, and S. E. Newman, in *Knowing, Learning, and Instruction. Essays in Honor of Robert Glaser* edited by L. B. Resnick, Hillsdale, NJ: Lawrence Erlbaum Associates, 1989, pp. 453-494.
2. J. Lave and E. Wenger, *Situated learning. Legitimate peripheral participation*, Cambridge: Cambridge University Press, 1991.
3. A. Sfard, *J. Learn. Sci.* **16**, 565-613 (2007).
4. A. Collins and W. Ferguson, *Educ. Psychologist* **28**, 25-42 (1993).
5. E. Etkina, Ph.D. thesis, Moscow State Pedagogical University, 1997.
6. J. B. Birks, *Rutherford at Manchester*, New York, NY: WA Benjamin, 1962.
7. M Born, *Experiment and Theory in Physics*, London: Dover, 1956.
8. E. Etkina, A. Van Heuvelen, S. White-Brahmia, D. T. Brookes, M. Gentile, S. Murthy, D. Rosengrant, and A. Warren, *Phys Rev. ST Phys. Educ. Res.* **2**, 020103, (2006).
9. D. Hammer, *Cogn. & Instr.* **12**, 151-183, (1994).
10. M. B. Baxter-Magolda, *Rev. Higher Educ.* **15**, 265-287, (1992).
11. E. Etkina, Anna Karelina, Maria Ruibal-Villasenor, D. Rosengrant, R. Jordan, & C. E. Hmelo-Silver, *J. Learn. Sci.* **19**, 54 - 98, 2010.
12. E. Etkina, Anna Karelina, & Maria Ruibal-Villasenor, *Phys. Rev. ST Phys. Educ. Res.* **4**, 020108, 2007.
13. E. Etkina and A. Van Heuvelen, in *Research-Based Reform of University Physics* edited by E. F. Redish and P. J. Cooney, www.compadre.org/per/per_reviews/media/volume1/isle-2007.pdf, 2007.
14. D. M. Desbien, Ph.D. thesis, Arizona State University, 2002.
15. D. Hestenes, M. Wells, and G. Swackhamer, *Phys. Teach.* **30**, 141 - 158, 1992.
16. R. R. Hake, *Am. J. Phys.* **66**, 64 - 74, 1998.
17. E. F. Redish, in *Proceedings of the Enrico Fermi Summer School, Course CLVI* edited by E. F. Redish and M. Vincentini, Italian Physical Society, 2004, pp. 1 - 65.